Stellar Parameters from photometry

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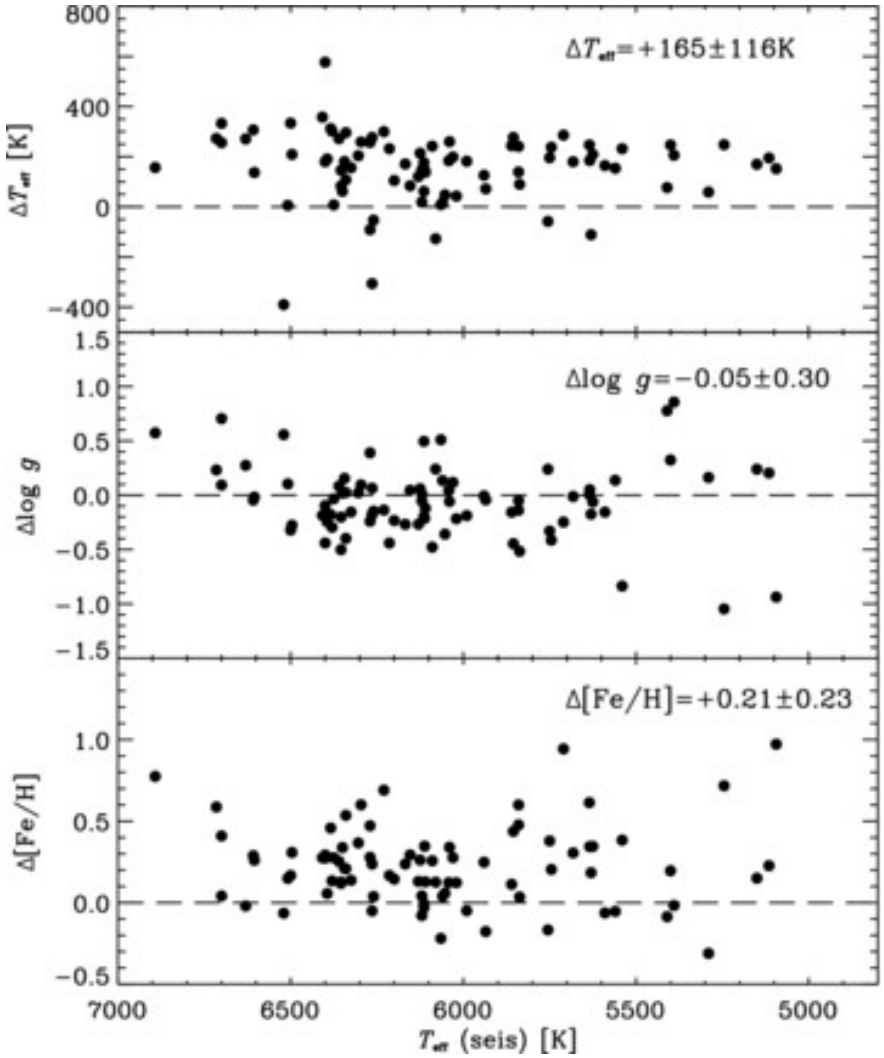
KIC Photometry

- KIC catalogue photometry and parameters
  - Brown et al., 2011, AJ, 142, 112
- Overall accuracy
- T_{eff} ±300K
- Log g ±0.5 dex for dwarfs
  - giants larger
- [M/H] can be off by over 1dex!
- Revised Teff scale
  - Dwarfs 200K hotter
    - Pinsonneault et al., 2012, ApJS, 199, 30



Bruntt et al, 2012, MNRAS, 423, 122

Fundamental Stars

A Fundamental Star is one with at least one atmospheric parameter obtained without reference to model atmospheres.

Ideally a Fundamental Star will have both parameters measured.

- Effective Temperature (flux and angular diameter)
- Surface Gravity (mass and radius)

Vital for the quality assurance of our spectroscopic parameter analyses

Observable quantities

$$\sigma T_{eff}^4 = F_\star = \frac{\theta^2}{4} f_\oplus$$

- $f_\oplus$ total flux at earth (UV, optical, IR)
  - **Beware of interstellar reddening**
- θ is angular diameter
  - Directly: speckle photometry, interferometry, lunar occultations
  - Indirectly from eclipsing binary systems with known distances

Surface Gravity

$$g = g_{Sun}\frac{M}{R^2} \quad \text{or} \quad \log g = \log M - 2\log R + 4.437$$

- Directly given by stellar mass and radius.
  - A measure of photospheric pressure
- Direct measurement from eclipsing spectroscopic binaries
- *Semi*-Direct from planetary transits and asteroseismology.

Accuracy of Direct Measurements

Sun (G2V)

- T_{eff} = 5777 ± 5K
- log g = 4.4374 ± 0.0005

Vega (A0V)

- T_{eff} = 9640 ± 100 K
- log g is not directly determined

Procyon (F5IV-V)

- T_{eff} = 6530 ± 90K
- log g = 3.96 ± 0.02 (Kervella et al. 2004)

Uncertainties in T_{eff} mostly due to uncertainty in stellar fluxes

Indirect Methods

- Direct determination is usually impractical.
- Have to use indirect methods
  - Photometric calibrations
  - Spectrophotometric flux fitting
  - Infrared Flux Method (IRFM)

Photometric Systems

- Will discuss the following photometric systems
  - Johnson UBVRI
    - colour – Teff relations, useful for SED creation
  - Stromgren uvbyβ
    - Good calibrations available
- Good review of photometric system by Bessell 2005, ARA&A, 43, 293

T_{eff}-colour relationships

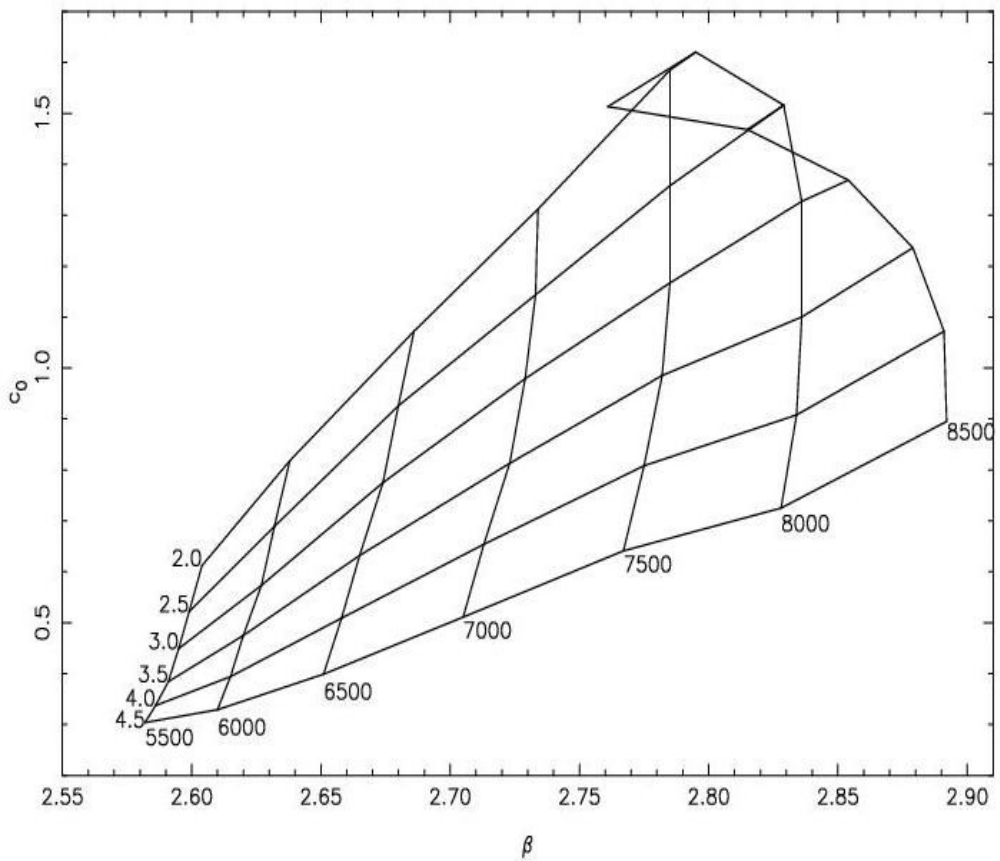
- Empirical calibrations based on stars with known temperatures, often using the IRFM.
  - Relations for broadband (UBVRI, JHK) and narrowband (uvby) photometry
  - Many examples, e.g.
    - Casagrande, et al., 2010, A&A, 512, A54
- Several steps involved in obtaining calibrations

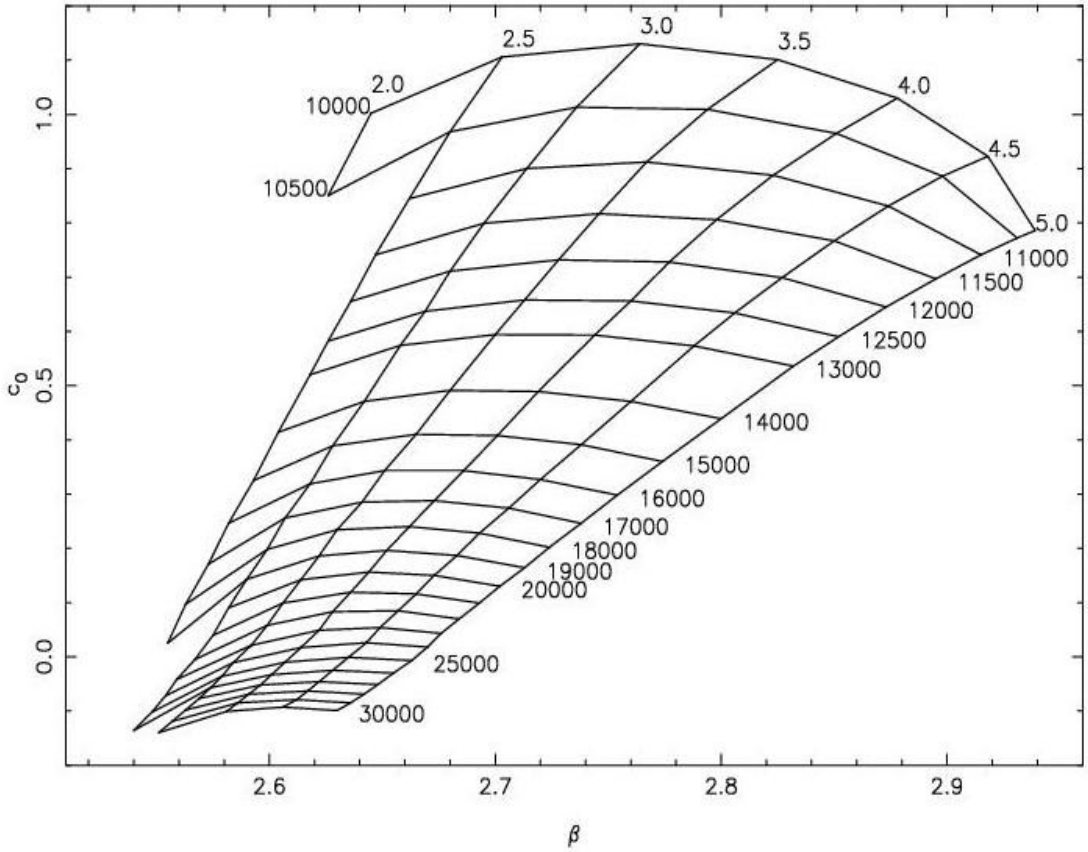
The uncertainties and final error on the parameters obtained to always obvious.

Strömgren uvbyβ photometry

- Four intermediate band filters (Strömgren 1966, ARA&A, 4, 433), plus pair Hβ filters (Crawford 1958, ApJ, 128, 185).
  - Four indices: b-y, c_1, m_1, β
- Dereddening routine UVBYBETA (Moon 1985),
  - Available in the IDL Astro Lib:
    - http://idlastro.gsfc.nasa.gov/ftp/pro/astro/uvbybeta.pro
- Parameter determination using grid calibrations. TEFFLOGG (Moon 1985) based on Moon & Dworetsky 1985, MNRAS, 217, 305)
  - Small corrections to log g by Napiwotzki et al., 1993, A&A, 268, 653
- Other calibrations are available

uvbyβ Grids





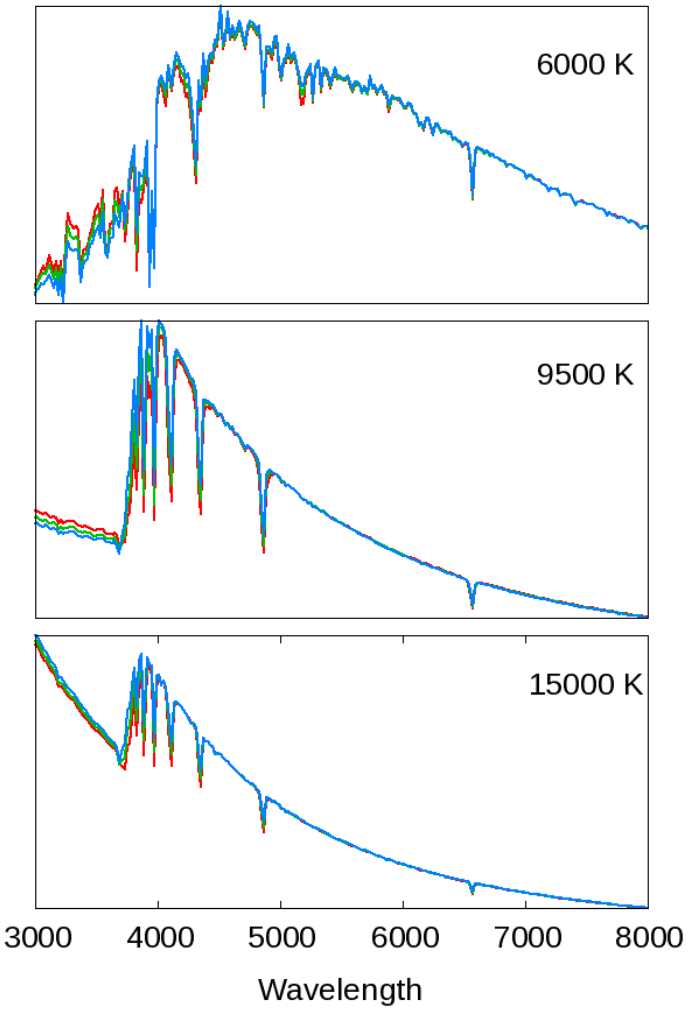
Smalley & Dworetsky, 1995, A&A, 293, 446

Spectral Energy Distribution

- What can we use for stars in Kepler Field?
- Ultraviolet
  - TD1 for brightest stars; IUE final archive for some stars; GALEX (only two UV bands)
- Optical
  - Spectrophotometry is limited for Kepler field
  - Estimate using broad-band photometry (e.g. UBVRI, SDSS, KIC, Tycho, TASS)
- Infrared
  - 2MASS J,H,K photometry; WISE

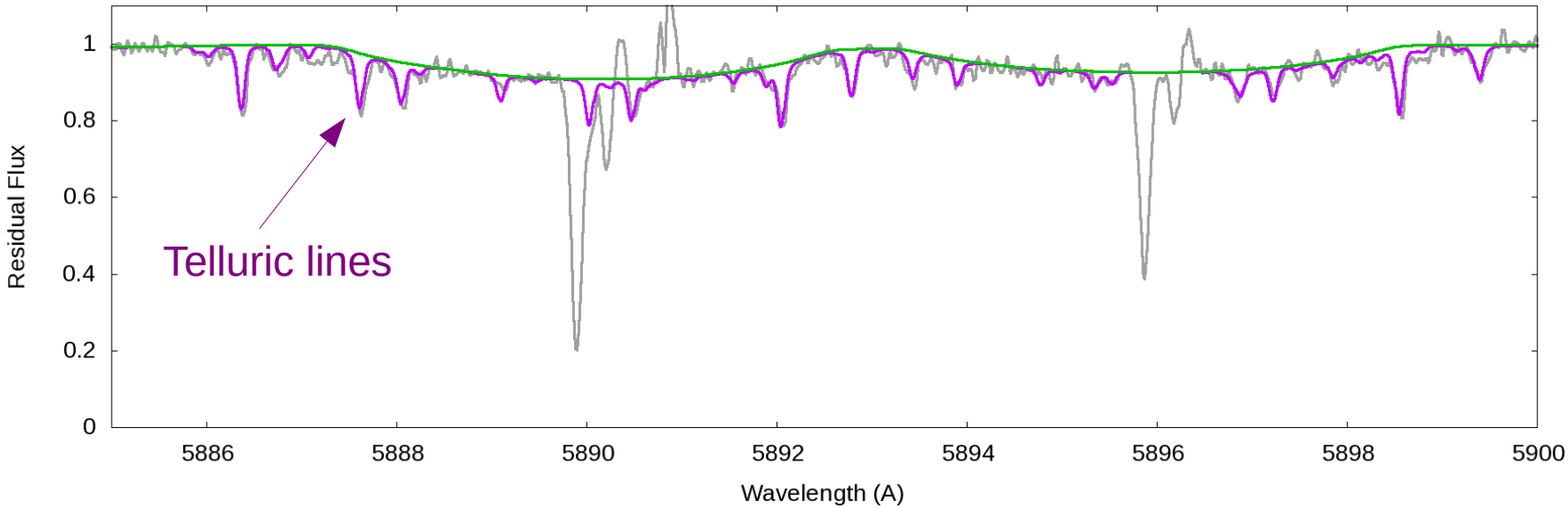
Flux fitting

- Fitting model fluxes to observed spectral energy distributions
  - Fit both T_{eff} and log g, simultaneously
  - Sensitive to [M/H], especially cooler stars
  - Poor log g sensitivity



Changing log g from 4.5 (red) to 3.5 (blue)

Reddening

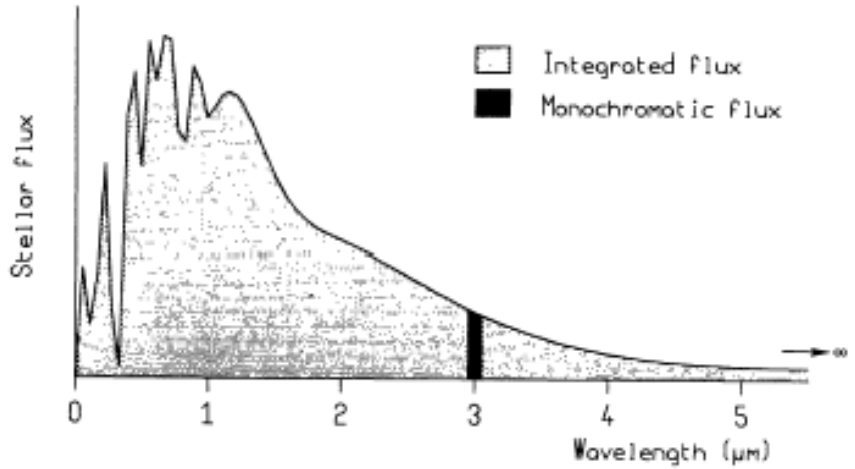


- Interstellar reddening can be estimated using Na D lines.
- Munari & Zwitter, 1997, A&A, 318, 269 calibration of 5890Å line.

- Example: KIC 11090405: Na D EW ~0.10Å →E(B-V) ~0.03

- If have UBV photometry of B stars, could use the Q-Method (Johnson & Morgan, 1953, ApJ, 117, 313; Heintze, 1973, IAUS 54, 231; see also Mayne & Naylor 2008, MNRAS, 386, 261)

InfraRed Flux Method



Blackwell et al. 1980, A&A, 82, 249

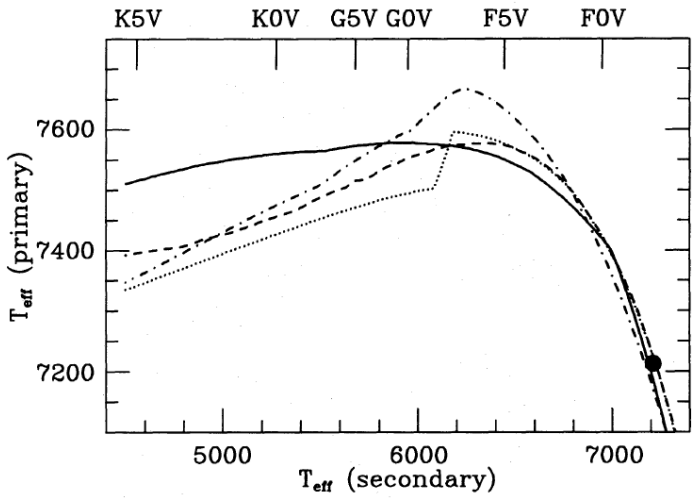
A good method for semi-direct T_{eff} determinations.
Also gives angular diameters (θ)

Beware of cool companions!

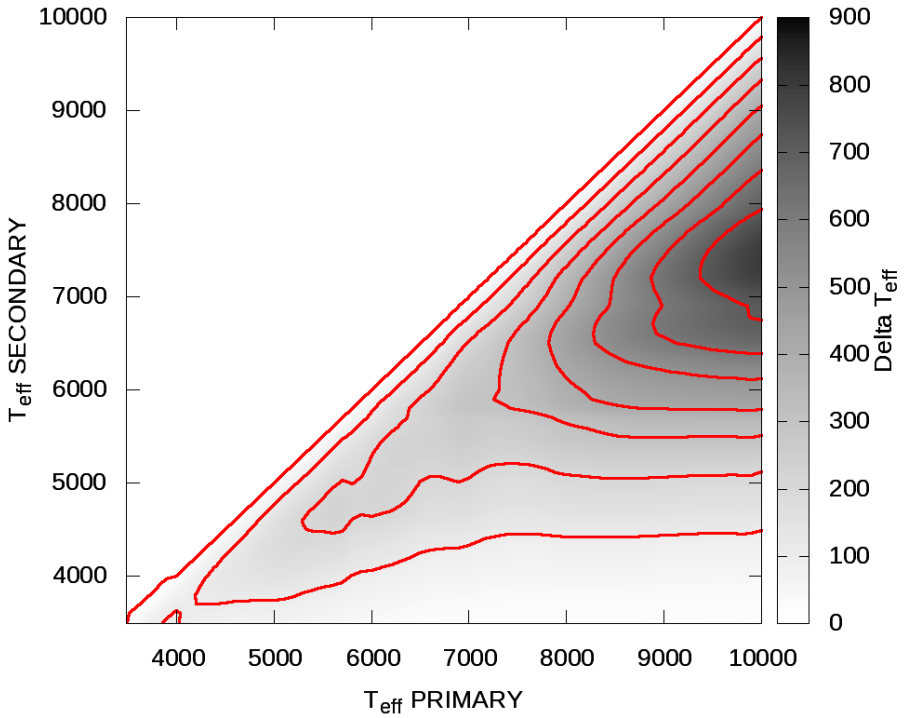
- Near Fundamental
  - Model to predict IR flux at stellar surface at given T_{eff}.
  - Good to 1~2%
    - e.g. Vega ± ~150K
- Beware uncertainties in absolute calibration of IR photometry alone
  - 2MASS: ~50K @ 6500K

IRFM and companion stars

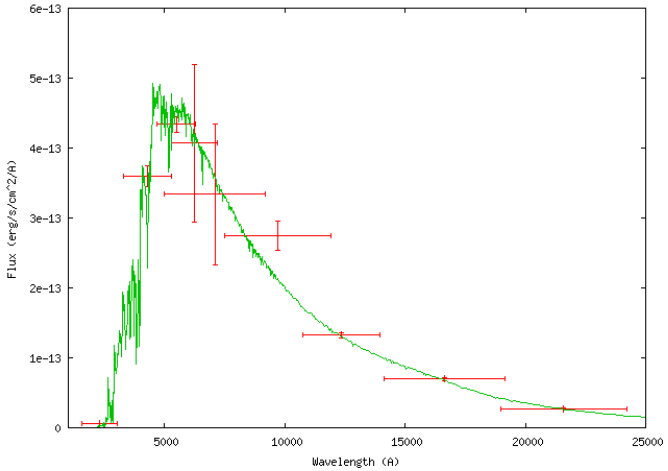
- Underestimates T_{eff}
- Need to allow for companion



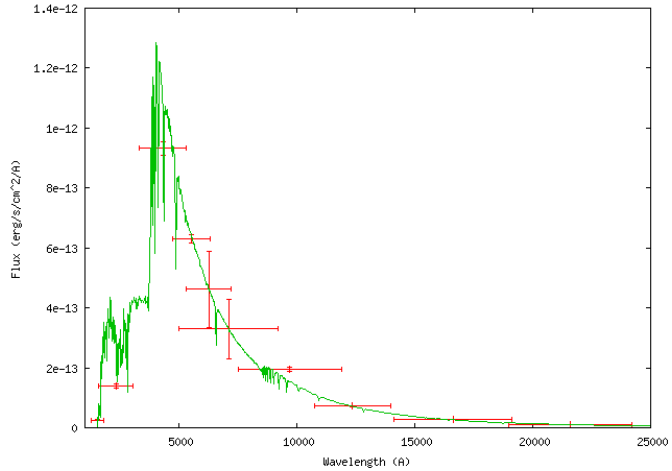
Smalley, 1993, MNRAS, 265, 1035



Flux Fitting Examples

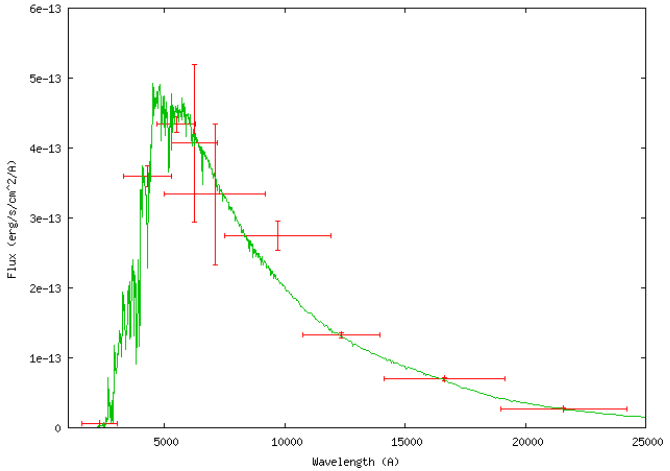


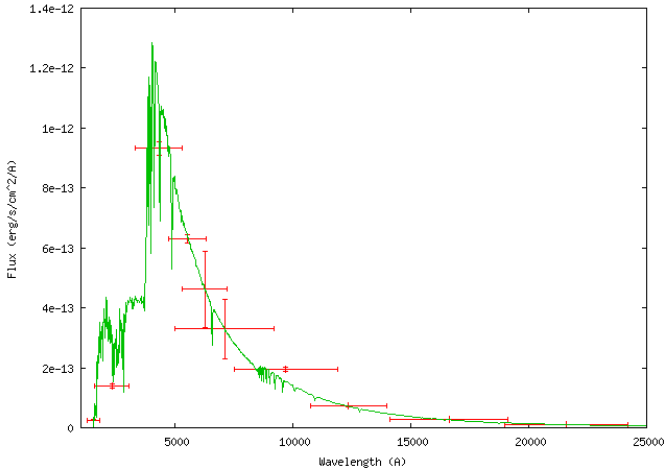
- KIC 11772920
- Model: T_{eff} = 5410 *log g = 4.50*
- $F_{\oplus}$ = (3.46 ± 0.17) 10^{-9} (erg/s/cm^2)
- IRFM: 5380 ± 130 K



- KIC 11090405
- Model: T_{eff} = 7980 *log g = 3.50*
- $F_{\oplus}$ = (4.24 ± 0.21) 10^{-9} (erg/s/cm2)
- E(B-V) = 0.03
- IRFM: 7970 ± 160 K

Flux Fitting Examples





- KIC 11772920

KIC 5175, 4.38, -0.54

- Model: T_{eff} = 5410 *log g = 4.50*
- $F_{\oplus}$ = (3.46 ± 0.17) 10^{-9} (erg/s/cm^2)
- IRFM: 5380 ± 130 K

Halpha ~5300 K

- KIC 11090405

KIC 7713, 3.70, -0.34

- Model: T_{eff} = 7980 *log g = 3.50*
- $F_{\oplus}$ = (4.24 ± 0.21) 10^{-9} (erg/s/cm2)
- E(B-V) = 0.03
- IRFM: 7970 ± 160 K

Halpha ~7500 K

Metallicity

- Stellar metallicity can affect the parameters obtained from flux fitting and broad-band photometry.
  - Not normally obtainable from these methods.
- The Strömgren δm_0 index can be used to estimate metallicity:
  - A-stars (Smalley, 1993, A&A, 274, 391)
  - F and G stars (Nissen, 1988, A&A, 199, 146, see also Önehag et al, 2009, A&A, 498, 527)

Summary

- Photometry can provide very valuable input in to the determination of stellar parameters.
  - Stellar fluxes and IRFM can give *near-fundamental* values of effective temperature
    - Good to 1~2%.
  - Intermediate-band photometry (e.g. uvbyβ) can yield values of T_{eff}, log *g* and [M/H]
    - Also estimates of reddening.